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Self–aligning Roller Bearings Fault Detection Using Asynchronous Adaptive Noise Cancelling

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Abstract: A new method is presented for increasing the signal to noise ratio from measurements of bearing housing vibration. The method is based on the conventional ANC technique principle, it makes some variation on the main signal input and reference signal input. Because the signal of the main and reference input are collected at the different time, this method is called asynchronous adaptive noise cancelling (AANC). It can improve the signal to noise ratio as to the case of the detecting bearing faults when vibration signal of machinery are collected under low frequency noise condition. Experiment result has shown that these techniques can be made more effective only after AANC has reduced the background noise from the diagnostic signals. A new approach is proposed to the traditional fault detecting.

Key Words: Bearing; fault detection; asynchronous adaptive noise cancelling;

INTRODUCTION: Methods of machine condition monitoring are now receiving considerable attention, on the premise that financial benefits can be obtained by reducing planned maintenance costs, by avoiding catastrophic failure and by increasing plants availability. The successful operation of a machine relies on the performance of each component element, e.g., bearings, shafts, foundation, and so an effective approach to overall machine monitoring requires a detailed understanding of the behavior of these elements and their interaction[9]. Condition monitoring and failure diagnosis of rolling element bearings is one of the most fundamental and important components in the mechanical system failure diagnostic technology.

Vibration monitoring is recognized as being an effective tool when applying a programme of machine condition monitoring. A lot of methods have been developed for localized faults of bearings. For example, statistical methods[9], time and frequency field analysis methods[3][10], analysis of bearings noise[14], adaptive noise cancelling technique[4], fuzzy and neural networks identification methods[2][12][15][16], etc.. But there is still not an ideal way to diagnose the early failure of the self–aligning roller bearing. Especially, the detection fault is fraught with difficulties, when the self–aligning bearing run in the condition of low speed. The signal to noise ratio is lower, and the impulse signal is more difficult to extract when the bearings are running at the high shaft speed condition.[16][7][1]

Adaptive noise cancelling (ANC), as this is widely known, is a method of estimating signals corrupted by additive noise. It has been applied to speech signals, electrocardiography, and adaptive antenna arrays.

It has also been applied to fault detection of bearings[4]. This method makes use of two signals input, a primary input, which contains the corrupted signals, and a reference input, containing noise correlated with the primary noise. Generally, the signals of primary input and signals of reference input are collected at the same time. The reference input may be derived from a sensor located at the point in the noise field where the signal is very weak. The signal to noise ratio will be affected if reference measurement point was unsuitably chosen. So, the correctly selected position of reference measurement point is very important, and also is difficult. The method can only cancel part of the noise resulted from the near component of machine or the machine, it can't completely cancel the heavy noise resulted from the normal vibration of bearings.

In this paper, a new diagnostic method is proposed to solve the problem that the success rate of fault detection is affected by the heavy low frequency background noise. Based on the idea of signal relative change, the abnormal running condition of bearings is an relative change as to normal running condition of bearings. The measurement points of primary and reference input are chosen at the same place (same sensor). The primary and reference signals are collected at difference time. Due to the reference input was collected at the early running time (normal running condition of bearing), and the primary input was collected at the present, this method is called asynchronous adaptive noise cancelling (AANC). It can eliminate unwanted normal background noise. The background noise includes normal vibration noise of bearings and noise machine vibration. Subsequent to applying AANC, enveloping spectrum analysis techniques were used for the purpose of detection and diagnosis of faults.

THEORY ANALYSIS: The Characteristic of Vibration Signals of The Self–aligning Roller Bearing: Due to the structure features of the self–aligning roller bearing, the rolling elements contact the inner race and outer race in line. Although the defect's pit of bearing is the same either in the ball bearing or in the self–aligning roller bearing, the degree of collision between rolling elements and defect's pit is not the same bigness, when each time a rolling element passes over a defect. The impulse's duration of the ball bearing is shorter than that of the self–aligning roller bearing. So, there are two main features in the vibration signals of self–aligning roller bearing. First, there are no short and sharp impulse signals enough in the vibration signals of self–aligning roller bearing. Second, the vibration signals of self–aligning roller bearing contain heavy low–frequency noise. Based on the these two features of vibration signals of the self–aligning roller bearing, the AANC technique can be used to improve the signal to noise ratio under the condition of heavy background noise of low frequency.

The Method of Asynchronous Adaptive Noise Cancelling: The special principle of AANC is shown in Fig. 1. The signal S is corrupted by a noise N_0 and received at the primary sensor when the bearing was running in abnormal condition. Where S is fault signal of bearings, N_0 is noise of machine that it contain normal vibration of bearings. A reference noise N_1, which is related to the noise N_0 in some unknown way but uncorrelated with the signal S_0, is received at the reference sensor. The vibration signals of self–aligning roller bearing is mainly relative to the shaft speed. Under the shaft speed is a steady constant, collected primary input and reference input at different time can satisfy the three assumption conditions of adaptive noise cancelling. The three assumption conditions have been shown in the paper[4]. Its were:

(1). S, N_0, N_1, and y are statistically stationary and zero means.

(2). S is uncorrelated with N_0 and N_1.

$$E[SN_0] = 0$$
$$E[SN_1] = 0 \quad (1)$$

(3). N_1 is correlated with N_0.

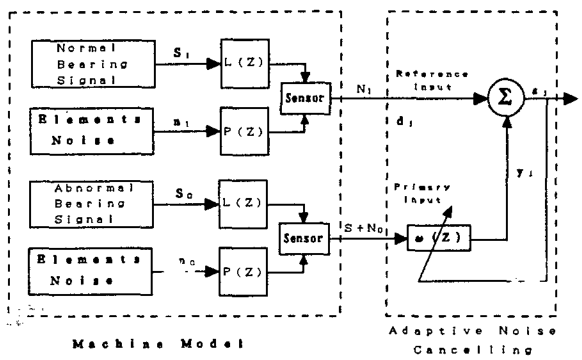

Fig. 1 The Model of An Asynchronous Adaptive Noise Cancelling

The output of the ANC system is given by

$$C=S+N_0-y \quad (2)$$

then

$$C^2=S^2+2S(N_0-y)+(N_0-y)^2 \quad (3)$$

$$\because y=W_j^TX_j \quad (4)$$

Where W_j is weight vector at the jth instant of time, X_j is reference input vector.

$$\therefore C^2=S^2+2S(N_0-W^TX)+(N_0-W^TX)^2 \quad (5)$$

Taking the expectation of both sides of equation

$$E[C^2]=E[S^2]+E[(N_0-W^TX)^2] \quad (6)$$

The signal power $E[S^2]$ will be unaffected as filter weights are adjusted to minimize $E(C^2)$

$$\min E[C^2]=E[S^2]+\min E[(N_0-W^TX)^2] \quad (7)$$

For an optimal set of filter output y is then the best least square estimate of primary noise N_0. From equation:

$$(C-S)=(N_0-y) \quad (8)$$

Adjusting the filter weights to minimize the output power thus causes C to be a best least square estimate of the signal S.

EXPERIMENTAL SET–UP AND DATA ACQUISITION: The experimental self–aligning bearings are a bearing type of NSK 22207. These bearing could be artificially localized defects induced by electric–discharge machine. The bearing failure occurs with defects in the outer race. The experimental data include two failure size types of self–aligning bearing under two kinds of shaft speed and one load. The test conditions are shown in Table 1.

Fig. 2 shows the bearing, housing, and the structure supporting them as well as the drive. The motor was connected to the driven shaft on which the aid bearings and test bearings were housed by a belt and pulley system. The motor was controlled by an alternating governor system (FUJI Frenic 5000 G9S/P9S). The vibration was measured with conventional, piezoelectric accelerometers. The signals passed through a multi–path A/D board and then the computer, where signals were analyzed. The software not only contains time and frequency domain signals analysis system, but also the digital adaptive filter of asynchronous and a digital low–pass filter. A time domain data set contains 8 samples, a sample has 1024 points. Spectra are averaged over 8 samples with a HANNING window. A figure of enveloping spectrum was drawn by using 512 points. The enveloping spectrum of AANC (after the application of AANC) was drawn by using 256 points.

Table 1 The Experiment Conditions

Name of set up condition	Value of set up	Frequency of outer race
Defect Type 1	2.6x1x0.5 (LxWxH mm)	
Defect Type 2	3x1x0.5 (LxWxH mm)	
Shaft speed 1	417 r.p.m.	44 Hz
Shaft speed 2	1667 r.p.m.	180 Hz
Load	5 kN	

Generally, frequencies of outer race and inner race or roller malfunction were used on identification faults of bearings. For feature frequency of the malfunction of inner race, outer race, or roller, there are formulas for calculating the frequency regions in which features may appear in the spectra[10].

$$F_i,F_o = \frac{n}{2} f_r \left[1 \pm \frac{d}{D} \cos \alpha \right] \tag{9}$$

$$F_b = \frac{D}{d} f_r \left[1 - \left(\frac{d}{D} \right)^2 \cos^2\alpha \right] \tag{10}$$

where f_r is shaft rotation frequency, F_i and F_o are frequenies for inner and outer race malfunction, respectively, F_b is frequencies for ball malfunction, d is the rolling element diameter, D is pitch diameter, n is the number of rolling elements, α is contact angle.

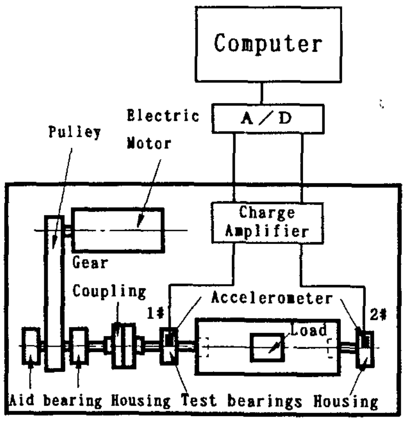

Fig. 2 Experimental Set–up

DISCUSSION OF RESULTS: This paper presents the results of asynchronous adaptive noise cancelling for the cases referred to in Table 1, the results of the time waveform, enveloping spectrum (before and after the application of AANC) are also given to show the effectiveness of AANC in eliminating the unwanted noise.

Fig. 3A and Fig. 3B show the normal signal of bearings when the self–aligning bearings were running at the 417 r.p.m and 1667 r.p.m.. They are also the reference signal of AANC. The capital letter A flag of figures show defect type 1. The capital letter B flag of figures show defect type 2. From Fig. 5 to Fig. 8 show two defect types at a shaft speed of 417 r.p.m. From Fig. 9 to Fig. 12 show two defect types at a speed of 1667 r.p.m.

Detecting the faults of bearing are difficulty as to signals of vibration when the bearings are running at the low speed and the small size of defect is small. There are heavy low frequency background noise when the bearings are running at the low (417 r.p.m.)or high shaft speed (1667 r.p.m.). Fig. 4 and Fig.6 also show the heavy disturbance of low frequency whether the bearings have defect or no defect. For example, near 228 Hz and 487 Hz have bigger value of amplitude.

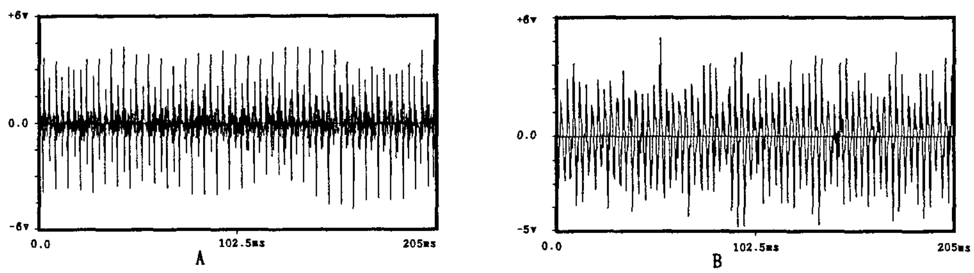

Fig. 3 Normal Time Waveform of Vibration Signal of Self–aligning Bearings

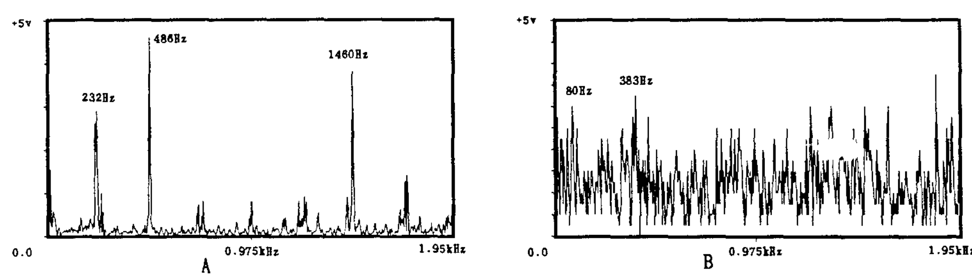

Fig. 4 The Enveloping Spectrums of Normal Signals

A comparison of the estimated bearing signal waveform Fig. 11 with the raw bearing signal Fig. 5 shows these two waveforms are similar. In Fig. 7 and Fig. 11 , the impact waveform is more clear than the raw bearing signal waveform. The heavy low frequency background noise has been eliminated, but the faults recognition still is difficulty by time waveform.

In Fig. 8 and Fig. 12 the defective bearing waveform is shown along with its enveloping spectrum (before and after the application of AANC). The enveloping spectrum clearly shows the amplitude of the fault bearing waveform after the application of AANC. The failure frequency of outer race can be found at the 42Hz and 46Hz in the Fig. 8, but it is not very clear to see from spectrum. The case may be resulted from resolution of spectrum, the resolution is 10Hz in Fig. 8 and Fig.12.

In contrast to this, Fig. 6 and Fig. 10 can find out about four times frequency of outer race, but it is difficulty to recognize faults of bearings. However, the failure frequency of outer race can be found clearly from Fig. 8 and Fig. 12. It has been shown that the signal noise ratio can be well improved by ANNC method under heavy low frequecy noise condition.

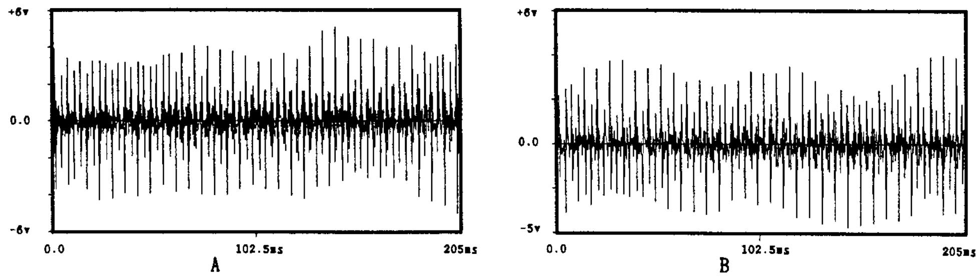

Fig. 5 Defect Type 1 Time Waveform

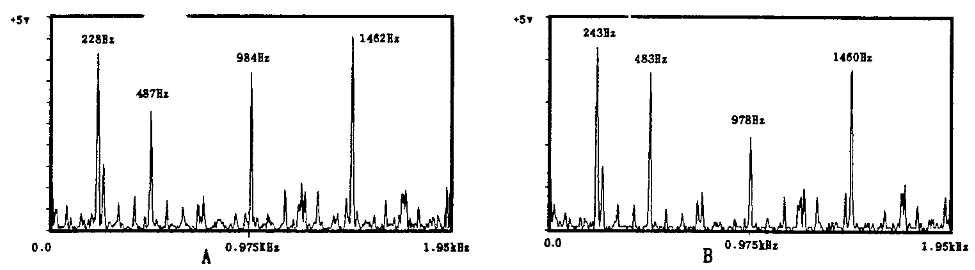

Fig. 6 Defect Type 1 Enveloping Spectrum

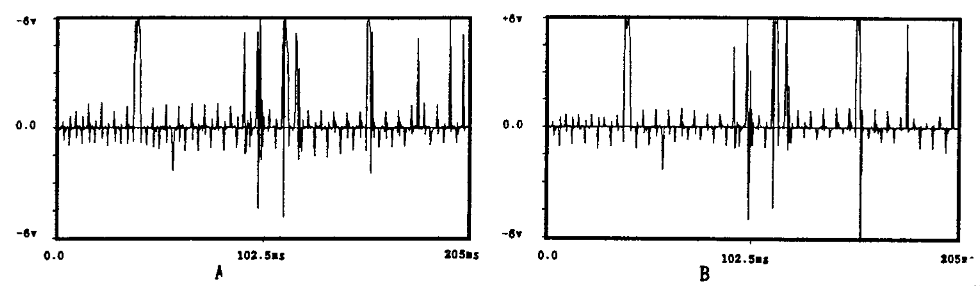

Fig. 7 Defect Type 1 Time Waveform After AANC

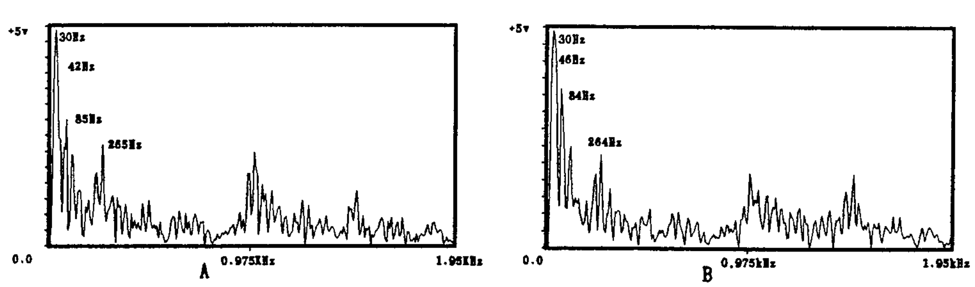

Fig. 8 Defect Type 1 Enveloping Spectrum After AANC

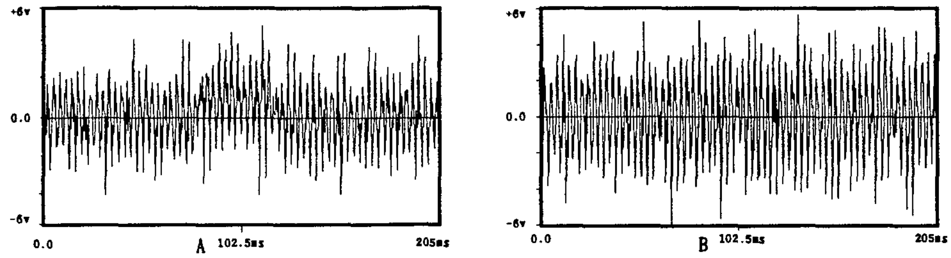

Fig. 9 Defect Type 2 Time Waveform

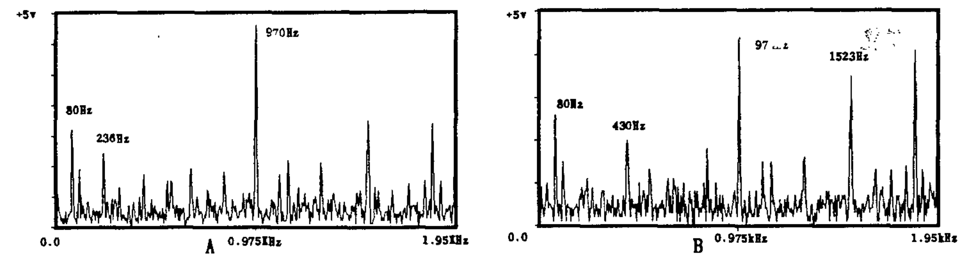

Fig. 10 Defect Type 2 Enveloping Spectrum

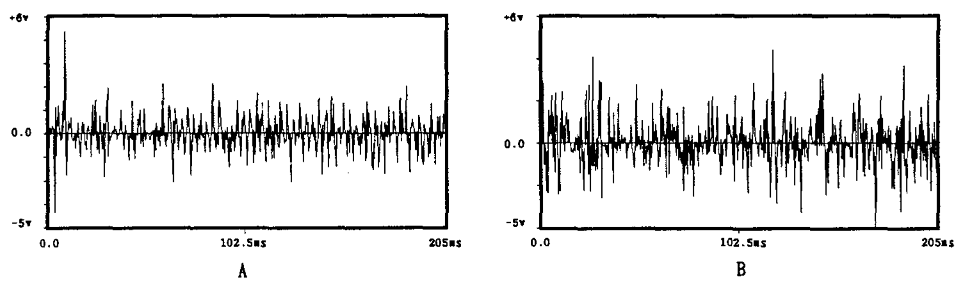

Fig. 11 Defect Type 2 Time Waveform After AANC

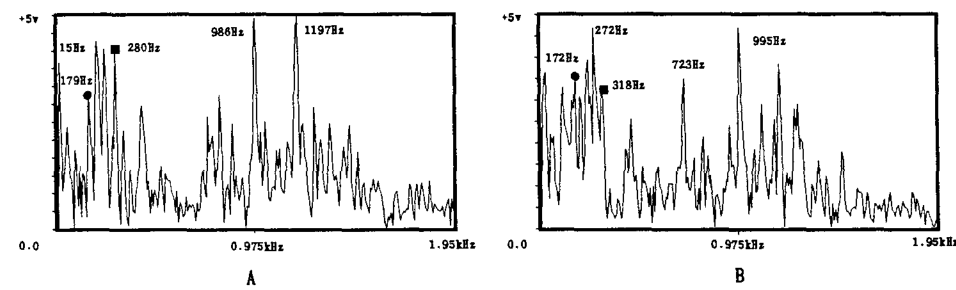

Fig. 12 Defect Type 1 Enveloping Spectrum After AANC

CONCLUSION: It has been shown that AANC method is a potentially powerful method to identify faults when the bearing was running at low speed or defect size of bearing is small. It is more effective for self-aligning bearing fault detection and diagnosis when combining AANC with enveloping spectrum analysis technique.

This paper proposes a variation of ANC for those situations where the main input signal and reference input signal are collected at the same sensor from bearing's housings. It can not only increase the signal to noise ratio under heavy low background noise, but also simplify measurement location choice. The technique enhances traditional fault detecting of self–aligning bearing.

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